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COON BUTTE, ARIZONA.

BY BENJAMIN CHEW TILGHMAN.

In Central Arizona, situated at approximately longitude $111^{\circ} 1'$ west and latitude $36^{\circ} 2'$ north, about five miles almost due south of Sunshine Station on the line of the Atchison, Topeka & Santa Fé Railroad, is situated the very remarkable eminence known locally by the names of Coon Butte, Coon Mountain and Crater Mountain.

This so-called mountain consists of a circular ridge from 130 to 160 feet in height, surrounding an almost circular cup-shaped depression in the earth about 400 feet deep and varying from 3,600 to 3,800 feet in diameter. Viewed from the inside, the crest of the ridge is elevated from 530 to 560 feet above the level of the flat interior plain.

The strata penetrated by this hole are, first, from twenty to forty feet of red sandstone; second, about 250 to 350 feet of a yellowish silicious limestone, or possibly more correctly a very calcareous sandstone; third, an unknown depth of a whitish or light gray sandstone, consisting of rather small water-worn grains but weakly attached to each other; fourth, about 80 to 100 feet of brownish sandstone in which it terminates. The contact between these latter strata is some 880 feet below the floor of the crater, but there is some reason to think it may not be in place but below its original position. These strata are of late Carboniferous formation, and in the surrounding plain lie perfectly level and conformably with each other. The uppermost, the red sandstone, being almost removed by erosion and only showing in spots upon the plain in the form of more or less scattered flat-topped red buttes, although it seems to have been nearly or quite continuous over the area now occupied by the interior edge of the crater.

These same level strata cover the plain in all directions for many miles. They are cut through by Cañon Diablo to a depth of some sixty to seventy feet about two miles to the westward of the crater, and near this gorge are two large earth cracks penetrating the strata to an unknown depth.

Immediately around the crater the strata dip outward in all directions from the center of the crater at an angle of about thirty degrees, and are raised from 140 to 180 feet above the normal position. This is the locality in which the Cañon Diablo meteoric iron has been found to the

amount of some ten to fifteen tons, and the question as to whether or not the hypothetical main body of the meteorite formed the crater in question in its impact with the earth has been the subject of numerous speculations and papers, notably by Professor Gilbert, of the United States Geological Survey, and others. The shape and general appearance of the crater, together with the absolute and entire absence of all evidence of volcanic action in or around it, manifestly inclined these early observers to decide this question, at least tentatively, in the affirmative, and they regarded the matter as worthy of further investigation. In pursuance of this object Professor Gilbert devised what he at the time, regarded as two crucial experiments to determine the presence or absence of a large amount of meteoric iron in the bottom of the crater. These were, first, a topographical survey of the hole and rim by which he made their contents approximately equal, and therefore gave no room for the presence of the bulk of the very considerable body required to produce such a hole by its impact; and secondly, a magnetic survey of the locality, which by its negative results was thought to preclude the possibility of the presence of any considerable mass of metallic iron in the vicinity. By these two experiments the question seemed to be authoritatively decided in the negative and the whole matter has remained in abeyance for many years.

The author of this present paper, having had his attention called to the matter by his friend Mr. D. M. Barringer, has examined the locality with great care, and with Mr. Barringer has done a considerable amount of development work there, and as a result of the facts disclosed thereby is very strongly of the opinion that the hole and its rim were produced in exactly the way at first supposed by the earlier investigators, and wishes here to bring to notice several points in support of the correctness of this theory which have escaped notice, or at least mention, in the papers of the earlier investigators of this most interesting locality.

It is first, however, necessary to criticise the so-called crucial experiments of Professor Gilbert, upon the results of which he definitely abandoned the theory of the meteoric formation of the crater in question, as, if these can be regarded as definitely settling the matter in the negative, there is no use in bringing forward facts looking towards its probability, no matter how plausible they may be. In regard to the first of these crucial experiments, that is, the alleged identical contents of the rim and the hole. In reply to this it can only be said that the author has also made surveys of this locality, and is very sure that the contents of the rim not only does not show the excess over that of the

hole that would allow for a large buried meteorite in the latter, but that it is short by many, at least several million, cubic yards of the quantity necessary to fill the hole at all. This, of course, if correct, and of that the author has no doubt, entirely destroys the weight of Professor Gilbert's reasoning, which was based on the assumed fact that everything ejected from the hole still remained around it. The solution is, of course, that in the time since the impact the rim has been reduced to its present dimensions by erosion, and the reason why it is or was so particularly subject to erosion will be taken up later when the formations of the rim are discussed more in detail.

As to the absence of sufficient magnetic perturbation, this is on its face a much more serious objection, as it undoubtedly proves the absence of any *one* large mass of iron near the locality, whether magnetized itself or only magnetized by the induction of the earth's magnetism, and also the absence of a mass of fragments of a magnetically neutral but magnetically permeable character magnetized by the inductive action of the earth. But it would have no bearing whatever as to the presence or absence of a mass of magnetized fragments each having sufficient coercive force of its own to be independent of the earth's inductive action, to the extent at least of retaining its own proper polarity irrespective of the position in which it is placed in regard to the terrestrial magnetic field. Such a mass of polarized fragments would form a series of closed magnetic circuits with practically no external field whatever. In support of this the following experiment was made. Two little cubes of magnetite about half an inch on one side were taken, which, as nearly as could be observed, had about the same effect on the magnetic needle. The weaker of the two, if there was any difference, was preserved intact, and the stronger was carefully broken up without loss to about the size of coarse sand. These fragments were then packed in a paper case but little larger than the original piece had been. It was found that this had to be approached to within an eighth of an inch of the compass needle to produce the same deflection that the original piece did at eight inches. Not only this, but it was found that one single grain of the sand-like fragments of the pulverized magnetite had more effect upon the compass needle when taken alone than the whole mass of them had when taken together. If the attraction of the mass of fragments of the supposed iron meteorite could be reduced in this proportion to its normal attraction when in a single piece, it might, on Professor Gilbert's own figures, lie within a very short distance of the surface of the present bottom of the hole.

The only remaining questions in regard to this so-called crucial experiment are: First, could the meteorite be reduced to this condition of physical wreck? and second, do the fragments have the necessary inherent magnetism? As to the last requirement, the overwhelming majority of the fragments picked up on the surface, probably ninety-eight per cent., do have this much magnetism, and some much more, and there is no reason to believe that the fragments of the main mass, if there be such, differ much, if any, in this regard from pieces collected on the surface.

Now, as to the probability of the shock of the collision breaking up the body of a solid iron meteorite of considerable size to sufficiently small fragments, it can only be submitted that the velocity and shock were enormous, and that it has been shown that ordinary soft iron at the temperature of liquid air is of about the brittleness of glass under the shock of a blow. Now, as it is practically certain that the body of such a falling mass would be at the actual absolute zero of space beneath its incandescent exterior, it seems much more than probable that the result of such a collision would be to reduce the projectile to an extremely fine state of subdivision in comparison with its original size. If these conditions of subdivision and magnetism are present, and it seems much more than probable that they are, the crux of the second crucial experiment is also escaped and we may proceed to consider the question on its merits, as nothing forbids us from allowing the possibility that the wreck of a great iron meteorite may underlie the bottom of the crater of Coon Butte.

DISTRIBUTION OF IRONS AROUND THE HOLE.

The early accounts of the locations of the finds of irons about this locality the author regards as of very doubtful value, for the reason that the great majority of these finds have been made by persons who were engaged in the occupation of selling them to museums and collectors, and who naturally did not wish to disclose the source of their supply to others. Also, these previous finds have been principally of large size, big enough in fact to enable them to take quite a divergent trajectory from that of the main mass, and too few to enable any reliable generalization to be drawn from their locations, even if the latter could be regarded as thoroughly reliable.

In the last two years the author and men in his and Mr. Barringer's employ have picked up more than 2,000 such irons, ranging in weight from 200 pounds down to a small fraction of an ounce, and have plotted the position of these finds upon a chart which shows plainly that the

principal locality for such finds is in the shape of a crescent surrounding the hole and strictly concentric therewith, and embracing its edges from the northwest to the east and having its line of greatest density about midway between these two points. These directions are taken from the center of the hole. The above distribution is by the number of finds regardless of their weight, as that of the scattering outlying finds is as a rule so much greater than that of the nearer finds as to entirely disturb the symmetry of the distribution. Moreover, the disposition of the smaller irons, which from their irregular forms and light weight could not have been propelled far from the mass from which they separated, is of more importance than that of the larger fragments, which would have more liberty of independent motion.

DISTRIBUTION OF MAGNETIC OXIDE OF IRON AROUND THE HOLE.

In addition to the irons found around the hole there is a very considerable amount of magnetic oxide of iron similarly distributed, the disposition of which does not differ materially from that of the irons themselves. For although it is more generally distributed around the hole and the radius of the area upon which it is found is considerably greater, yet the fragments are arranged in the same general way with the axis of the group, which is also the line of greatest density of their deposition, extending away from the center of the hole in a direction between north and northeast.

PROOF OF THE METEORIC ORIGIN OF THE MAGNETIC OXIDE OF IRON.

The fact that this magnetite is of meteoric origin is proved from the following facts: First—It is found attached to and in some of the cavities of some of the larger irons. Second—Some of the larger pieces, although not the largest, are found to have centers of metallic meteoric iron. Third—The chemical analysis of the iron and the magnetite show a very close agreement between the proportion of metallic iron and the other metals present in the magnetite and in the meteoric iron. These other metals consist of nickel, cobalt, platinum and iridium, and another metal or metals of the platinum group. Fourth—The magnetite is fused and massive and at the same time stratified and laminated, and in general appearance different from any terrestrial magnetite known and closely resembles what would be thought, *à priori*, to be the appearance of such a product of iron melted and burned on the surface of a great meteorite in its passage through the air.

IDENTITY IN POSITION OF THE POINT OF IMPACT OF THE METEORITE
WITH THE CENTER OF THE HOLE, AND IDENTITY IN TIME OF THE
FORMATION OF THE HOLE WITH THE IMPACT OF THE METEORITE.

We thus have two different meteoric materials distributed over the rim of the hole and the surrounding plain on areas symmetrical about the same line, which is a line drawn in a north-northeasterly direction from the center of the hole. And also each of these areas closely embraces the hole and there terminates. For, with few exceptions, no iron nor magnetite has been found on the surface within the hole, and these exceptional pieces were found close to the wall, and may have fallen in by ordinary weathering action from the cliffs along with outside surface material. This brings these meteoric materials into close relation with the hole, which cannot be accidental, as if the shower of meteoric iron and magnetite fell after the formation of the hole, by other agencies, it is inconceivable that the densest portion of the shower of each material should coincide accurately with the northeasterly rim of the hole and yet none fall into it, although scattered individuals of each shower are found around the hole on all sides. Whereas, if the shower occurred before the formation of the hole, it is equally inconceivable that the fallen material could be found most thickly on the surface of the rim, composed of material ejected from the hole. To further assure the absolute identity in point of time of the fall of meteoric material and the formation of the hole, cuts and shafts were made in the débris composing the rim, and up to date over one hundred pieces of meteoric material have been taken from the ground, at distances varying from six inches to twenty-seven feet below the surface, mixed with the rim material and under large imbedded rocks. In many places it was absolutely impossible, from the slope of the ground and other circumstances, that they could have gotten where found except by simultaneous deposition with the broken material forming the rim. In one shaft seven pieces were found with fifteen feet of vertical depth between the highest and the lowest, which was twenty-seven feet below the surface of the ejected material.

THE RIM.

This consists, as has been briefly stated before, of a circular ridge of from 130 to 160 feet high closely surrounding the hole. A generalized description of its profile would be somewhat as follows: Beginning at a point on the inside of the hole on a level with the surrounding plain, the surface of the rim consists of the edges of the strata which should

normally be lying level some 150 feet below the surface. These strata themselves dip downward and outward from the center of the hole at an angle of, on the average, about thirty degrees, although this varies in places from more than vertical or inclining backward to about ten degrees. The strata themselves are crushed and shattered to an extraordinary degree, and the surface of the rim slopes upward and outward from the center of the hole at an angle of from fifty to eighty degrees; possibly sixty degrees would describe the general shape better than any other slope. Considering the shattered and disintegrated material of which these cliffs are composed, it is remarkable how little talus has fallen from them. This slope continues up almost to the top of the ridge, although here and there are flat benches in it both at the junction of the yellow limestone and the red sandstone and at partings in the red sandstone itself. From fifteen to forty feet from the top of the ridge on the inside is located the top of the red sandstone, which was the original surface of the plain; at the place of impact and from this point the ridge slopes outward at the ordinary sliding angle of loose materials, somewhat less than forty degrees, to its summit. The summit of the ridge is of necessity a closed ring and is sharply serrated into peaks, and the colls between these serrations do not exceed thirty to forty feet in depth but their slopes are steep, often ten to twenty degrees. There is a marked low place in the rim, extending over nearly one-sixth of its circumference on its northern side. On the outside no description will suffice for all sides. The greatest amount, by far, of the material thrown out of the hole is found in the southern quarter of its circumference, and here the rim is almost flat on top for a number of yards and then slopes outward at an angle of only seven degrees for some 900 feet, where it ends in a sharp slope of some twenty-five feet high at an angle of some twenty degrees. Beyond this is a thin cover of ejected material and detached and partly buried limestone fragments which extend for a considerable distance; some of the latter having been thrown nearly a mile from the edge of the hole. The actual surface of this southern side of the rim consists largely of blown sand, as the winds in the country are strong and storms frequent and their usual direction is from the southwest. On the eastern, northern and western sides the ridge is thin and sharp; in many places not over a yard or so in thickness at the very top and sloping outward very sharply, in places up to thirty degrees, for about half its height, and then more gradually at some five degrees until it joins the plain. The general surface of the outer slope is not at all a smooth cone of the angles above stated, but is cut up into hills and hollows and every

imaginable subfeature to a very great degree. This is almost entirely due to the irregularity of its deposition, slightly modified later by the action of water. The surface material of the outside of the rim, where it is not covered with blown sand, as on the southern side, is composed of the broken débris of the three strata through which the hole penetrates, piled together in the utmost confusion and disorder, pieces from all the three strata being thrown together in the most intimate mixture with a slight tendency towards inversion in the order of their deposition. That is, there is rather more of the red sandstone in the deeper portions of the rim than on the surface, while on the surface the limestone and white sandstone predominate, with here and there large areas of unmixed white sandstone lying on the surface. In size these fragments vary from huge rocks forty to fifty feet in length and weighing thousands of tons down to impalpable powder and all intermediate sizes, and many of the rocks are so crushed and broken that they barely hold together. And imbedded in the deposits of impalpable powder are many pieces still retaining the form of rocks, still showing the stratification and bedding planes distinctly, but so crushed as to have lost all solidity. These crushed rocks in many cases have been subjected to such pressure that not only is their consistency as rocks destroyed, but even a certain proportion of the sand grains composing them have been utterly destroyed and they can be rubbed between the fingers to a fine powder, the grains of which will average much less than that of the sand grains originally composing the stone.

This powder forms a very considerable proportion of the substance of the rim. It is not merely a filling material occupying the interstices between the rocks, as might be a rock pile with fine material water-washed or wind-blown into it until all the crevices were filled up solid. But it occurs in distinct deposits, sometimes alone and entirely free from rock fragments and sometimes mixed with a larger or smaller proportion of rock fragments. When this mixture occurs, the rock fragments are usually so far apart that each rock is entirely surrounded and supported by the powder. Such deposits of powdered rock are often overlaid by a cover of broken rock many feet thick, the individual rocks in places weighing a hundred tons or more. In fact, as far as at present developed, it seems to be a very general feature of the structure of the rim that the lowest material, that lying upon the top of the original surface, is a greater or less depth of this powdered rock, sometimes alone and sometimes mixed with rock fragments, and that on this rests and is supported the whole of the detrital cover which constitutes the crest and outer slopes of the rim.

THE INTERIOR OF THE HOLE.

From the point on the level with the exterior plain on the inside of the rim the walls of the hole slope downward and inward at a constantly diminishing angle for a distance varying from 50 to 150 feet, in the same formation as above described as the base of the inside of the rim. At this point the rock walls begin to be covered with a rocky talus corresponding in all respects with the rocky cover on the exterior of the ridge. For about half the circumference of the hole the yellow limestone extends downward to the talus, and for the remaining half it exposes more or less of the whitish sandstone below. The white sandstone is a much weaker rock than the yellow limestone, and at their contact it is noticed that the former is much crushed and disintegrated by the pressure exerted by it in lifting the limestone. This stratum of crushed sandstone varies in thickness up to some ten or fifteen feet as a maximum, and in some places, usually immediately below the limestone, it is reduced to a bed of sand grains absolutely unconnected with each other, and in places a small proportion of even the sand grains have been crushed and broken to fragments and powder.

The very top of the talus slope is in places at an angle of forty degrees, but usually much flatter down to thirty and twenty-five degrees, this rapidly becoming less and less as it recedes from the cliffs until it is lying at an angle of not more than six degrees at the point where it disappears under the central plain. This central plain is an almost circular area of about 1,800 feet in mean diameter, with a surface generally flat but gently rolling within a limit of fifteen feet, with its lowest point a few feet to the east of the central meridian of the hole and about sixty feet south of the center. Shafts have shown the rocky talus to extend under this central plain at about the same angle that it has above for a distance of at least 400 feet, at which point it is some forty-seven feet below the surface and about twenty feet thick. This talus does not extend entirely across the hole. It is absent at points 50 feet southwest and 200 feet southeast of the center of the hole. Exactly where it terminates is not known.

THE SILICA.

It is here necessary to describe more minutely the material of the filling of the central plain. This is identical with the impalpably powdered rock referred to briefly above in the description of the rim. This material, of which there are millions of tons in the rim and the bottom of the hole, consists of the rock of the strata concerned reduced

to an extreme state of subdivision. It seems to have been produced principally from the white sandstone, for it is mostly as white as snow and consists of over ninety-nine per cent. silica, although here and there small areas or deposits will be of a slightly yellowish color from the yellow limestone and contain a little carbonate of lime, although this has to a great extent been leached out of it, and much more rarely of a reddish color, either stained by or produced from the top stratum of red sandstone. Under the microscope it is seen to consist of minute fragments of clear transparent quartz with edges and points of extreme sharpness, and no signs of any wearing or rounding are anywhere visible upon its particles. In some areas the material is composed of this material exclusively and it gives no internal evidence of the manner of its production. But in other localities it can be found containing a greater or less percentage of broken sand grains among it which have escaped being crushed out of all recognizable shape. A continuous series of material can be found containing more and more *broken* sand grains and less and less silica (as we have gotten to call the impalpable powder, for want of a better short descriptive name), and then more and more *unbroken* sand grains, and then little bunches of sand grains still adhering together, and so on up to the solid sandstone rock. Its general microscopic appearance is identical with that of a handful of glass fragments produced by a blow. It cannot be quite imitated by grinding the sand grains in a mortar, as the edges and points of the powder thus produced are more blunted and rounder and broken than those of the silica. But it is very closely duplicated by the finest powder produced by firing a high power rifle bullet against a block of the sandstone.

THE INTERIOR OF THE HOLE (RESUMED).

In the central area over which the talus does not extend, the line of the original surface upon which the talus was deposited, and on which the subsequent filling, which now covers this and also a portion of the talus, was deposited, can be very readily recognized. All the material lying above the talus, and above this surface, is horizontally stratified and contains organic remains, such as small shells and no (or but very few and small) rock fragments, while that below this line has no trace of stratification nor of organic remains and contains many rock fragments. In one shaft a beautiful series of rock fragments was observed about twenty feet thick and about twenty feet below the talus, in which the natural order of the rock in place was exactly reversed; that is, the red sandstone was deepest and the yellow limestone and whitish sand-

stone in that order above it. This series naturally suggested the idea that the surface stratum, having received the blow and started on its aerial flight first when the hole was formed, finished its journey first and was consequently deepest imbedded in the silica which was in process of filling the hole made during the flight of these rocks in the air. Almost immediately after the fall of the last of this series—which must have fallen directly in place as found and which is comparatively rare, as the rocks expelled from the hole had usually (apparently) a greater outward radial component in the direction of their flight—came the rush of talus rocks, which fell in masses on the funnel-shaped cliffs surrounding the hole and forming the interior of the rim, and rushing inward covered the surface of the bottom of the hole to a considerable distance from the foot of the cliffs, in fact probably all except a small area of 300 or 400 feet in diameter in the center. Then, during minutes and hours, settled down over everything about the locality the dense cloud of dust to the depth of many feet. This dust, being the finer portions of the silica above described, was then washed into the center of the hole, filling it in some places a hundred feet deep. This was apparently done by successive wet seasons for many years, during which time, at least in the rainy season, a shallow lake occupied the bottom of the hole; over the bottom of which the sediments were distributed in yearly level strata by wave action. The presence of the rare stone fragments in these sediments and the few now on the surface of the interior plain, far beyond any possible place to which they could have rolled if detached and falling from the cliffs, is difficult of explanation unless it be due to a frozen condition of the central lake, on the surface of which these rocks (and they have not been observed of large size) could slide and on which a very slight initial velocity would take them to their present position, to be there deposited upon the melting of the ice. Ten to fourteen inches of ice was formed on the open water in reservoirs in this locality during the last winter.

No very exact estimate of the amount of this silica dust washed down from the sides of the hole can be made, as the shape of the original bottom of the hole is unknown. It is irregular and in places the sediments are 100 feet thick, and it covers an area of about 1,800 feet in diameter. Moreover, it evidently fills the interstices of the talus of unknown thickness extending over a much greater area. It can only be said that it is a very large amount, many million tons. It probably covered all of the exterior of the rim to an equal or greater depth, all of which is gone. In fact it seems extremely probable that the rock cover of the rim, which is now its most prominent feature, on the sur-

face of which both rocks and meteoric material are much more frequent than in the substance of the rim below, is itself a concentration of material like the present rim, below the rock cover, of mixed silica powder and rock, from which the silica powder has been washed away until the accumulated rock cover, and probably the decreasing rainfall of the country, has preserved the rim now remaining beneath this rock cover in its present form. Also, upon the accident as to whether or not there was a strong wind blowing at the time of the formation of the hole would determine whether or not a great portion of the fine powder produced ever settled on or around the rim at all. Hence, in the opinion of the author, the deficiency in the contents of the present rim to fill the existing hole, and this fact is also a valid objection to the use of their comparative bulks as having any bearing whatever upon the probability of the wreck of the great meteorite lying beneath the bottom of the hole.

THE TRACES OF THE LUMINOUS TAIL OF THE GREAT METEOR.

It occurred to the author that if the meteoric theory of the formation of this crater was correct, such a projectile falling through the atmosphere at the requisite speed must have been surrounded by the usual luminous tail always accompanying such objects. And that as no meteoric material except nickel-iron and magnetite containing nickel had been found in the vicinity, it was a fair deduction that the surface of such meteorite, if it ever existed, was of nickel-iron, and that the luminous tail in such case must have consisted of atomized particles of incandescent magnetite. Pursuant to this idea a search for this material was made with magnets about the locality, and it was found that its presence was absolutely universal over the whole locality inside the hole and out for as far as observed, somewhat over two miles from the hole. It consists of a blackish-gray rather fine-grained powder, strongly attractable by the magnet, crystalline in structure, but not at all so in shape, being in small torn irregular masses with generally intensely fine grains of silica powder adhering so firmly to its surface as to suggest adhesion while in a state of fusion. Of very rare occurrence among it are absolutely round balls with a fused polished surface like intensely fine shot. These, it is supposed, have had time to solidify in the vacuum behind the flying meteor free from the fierce rush of air that had solidified the usual grain in any shape whatever, and they were enabled thus to assume the usual shape of liquid drops.

With considerable labor enough of these particles were collected for analysis, and they were found to contain nickel in but little less

proportion to their iron than found in the irons themselves and in the larger pieces of magnetite. This is not a usual substance and, so far as known, is not a constituent of any of the rocks in the neighborhood of the area anywhere adjacent to the same.

ON THE FINE SILICA POWDER UNDER THE BASE OF THE RIM.

The meteoric theory of the formation of this hole being thought untenable by some previous investigators and the ordinary volcanic action being absent, there has been invoked, to account for its formation, the theory of a single steam explosion, and in fact this theory has been elaborated so far as to try to imagine a state of stress produced by steam which was set off by the blow of a small falling meteorite, much in the same manner that a percussion cap discharges a gun. This was evolved to account for the simultaneous deposition of the meteoric material and the rim. This has been urged in spite of the fact that during the time that the local heat had been increasing in the wet strata there would have inevitably been hot spring action, and that the same thing would have occurred long after the relief of the explosion, and that the traces of this action would have been but little, if any, less evident than those of ordinary volcanic action and are nevertheless totally absent. Yet there is one fact obvious to all observers to-day, to which the author desires to call attention, which makes any such theory of the explosive formation of the hole utterly impossible. This is the fact that the rim is generally founded upon a more or less deep layer of fine silica powder. There is no doubt that the rock fragments forming the rim were all deposited within a few seconds after the hole was made. The great majority were propelled too short a horizontal distance to have had a long trajectory in the air. Now if they had been propelled by a compressed elastic medium, it is evident that on the explosion these compressed gases would have instantly assumed a much higher velocity than the heavy rock particles to which they were imparting velocity and, sweeping by them, would have carried with them every particle of silica powder which had been made by the crushing and yielding of the strata to the strain, and the rocks of the rim would certainly and necessarily have fallen on the bare upturned stratum which had previously formed the surface of the ground around the edge of the hole. To account for the presence of this silica powder on the theory that the hole was formed by a great projectile requires a short preliminary study as to the yielding of hard, brittle and practically incompressible material before a projectile or other blow or even quiet pressure, for the method is much the same in both cases. Briefly, the

way in which such substances yield to either a pressure or blow in excess of their power of resistance is, that a cone of material with an apex angle of about ninety degrees is compressed downward into the solid mass of the material from the point of impact. This cone parts from the overlying material, crushes into powder under the force of the pressure or blow, and this powder being still further compressed transmits the pressure upon it in all directions, somewhat like a fluid, although not equally in all directions. The pressure thus generated in the very substance of the material seeks relief and forces a yielding of the solid material around it, which, of course, occurs along the line of least resistance, and bursts the surface upward and outward into a cone-shaped crater around the point of impact or pressure, the angle of which depends largely upon the nature of the material. With ordinary stone this is usually about thirty degrees, but always must be less than forty-five degrees, which is its limit. This crater-like cone is small at first and remains so for weak impacts or small pressures, but if these are greater the process is continued by the formation of larger cones of compressed powder, deeper in the body of the material, which relieve themselves by bursting up wider craters, until the force of the pressure or impact is no longer able to continue the process and the penetration ceases. Thus the depth of the crater always bears a definite relation to its width, and in large impacts it is found that the crater is always surrounded by a cone of cracked and shattered material, which would have been the next material to be expelled if the energy of the blow had been sufficiently great to accomplish this.

The bearing of this upon the formation of a rim composed in part of fine powder is as follows. The broken rocks and débris that are expelled from the hole get their velocity imparted to them by the push of an inelastic powder behind them and not by a compressed elastic gas, and thus when both rock fragments and powder have progressed far enough to free themselves from the pressure of the penetrating projectile they fly on together, mixed powder and rocks, at the same velocity. This powder is not dust in the ordinary acceptation of the word, as fine powder mixed with a large quantity of air which takes a long time to settle out, but is almost unmixed with air in solid masses, particle to particle, like flour in a barrel, so to speak, which masses obey the laws of projectiles and falling bodies, irrespective of the exceedingly minute particles of which they are formed, and are thus deposited in the rim in mixture with and under and over the solid rock masses which accompanied it in its flight, and as quickly; and the powder having started under the rock masses, there is a strong tendency for con-

siderable amounts to remain under them on the final deposition of the mixed masses of material in the rim of the hole after their expulsion.

THE CRUSHED SANDSTONE AT ITS UPPER CONTACT WITH THE LIMESTONE AND THE SHATTERED CLIFFS AROUND THE HOLE.

The author desires particularly to call attention to these features of the walls surrounding the hole. It is very distinctly marked. It is unquestionably due to excessive pressure. If this cone and crater are due to any form of volcanic action, it is difficult to see how this crushing occurred. The sandstone is amply strong to carry its over-burden without crushing; in fact before the general erosion of this country it probably carried many hundreds or thousands feet more without crushing and pressure from above or below as equal in its crushing effects. Then suppose pressure to gradually accumulate and the overlying strata to bulge up into the dome of which the present cone is the base; there could be accumulated but little excess of pressure to crush the sandstone during this rise, as it would be as free to go up under the weight of its overlying strata as it was to support them quiescent, for such motion would be very slow. Then comes the giving way and the explosion, and the result to the remaining rock left around the hole is a relief from pressure and not an increase of it. It is difficult under any of these conditions to imagine any force tending to crush this sandstone and shatter the surrounding walls in the manner that they are shown to-day. It is difficult to discuss the steam explosion theory, for the reason that nobody has ever seen one or known with certainty of any such action, except the blowing off of the tops or sides of ordinary volcanoes in activity in this manner, which is as different as possible in its effects from the so-called maars. There are a lot of holes, not very uniform nor congruous among themselves, which, for want of a better explanation of their formation, have been ascribed to this source, and to which class Coon Butte has been assigned by Prof. Gilbert, as the result of his investigations. This crushing of strata and shattering the walls is, however, the direct and obvious result of the blow of a great projectile. There is almost instantaneously generated an overwhelming pressure deep down in the rocks, tending to lift the surrounding strata at 1,000 or more feet per second. The great weight and inertia of these strata oppose an enormous obstacle to this sudden movement, and the crushing strains developed crush up the weakest rock until the necessary yielding and velocity have been imparted to the overlying strata. The shattered cliffs and upraised rim show the rock started from its position and in partial transition from the hole, from which it would have been

expelled entirely had the blow been a little harder. In this case, however, another rim of crushed and shattered rocks would have been upraised around the enlarged hole.

COMPARISON OF THE CRATER WITH THOSE PRODUCED BY LESSER
PROJECTILES.

The craters formed by the impact of various small projectiles, mostly of soft materials and at low velocities, have been studied in connection with the formation shown in this locality by others, notably by Professor Gilbert, and the forms shown to bear a rather close resemblance to the crater of Coon Butte and its rim. Continuing these comparisons, however, to more violent impacts of heavier bodies at higher velocities, a still closer parallel is noticed. The material for such comparisons is furnished by the investigations of the several more advanced military nations upon the effects of the impact of round shot on masonry and solid rock. These investigations were undertaken about sixty to seventy years ago, with the object of ascertaining the best effects of the ordnance of that day in the breaching of walls, etc., in bombardments. The general result was to establish the fact that the impact of the projectile produced a comparatively shallow crater of conical form about five times the diameter of the projectile, terminating in an almost cylindrical hole some one and a half to twice the diameter of the projectile within which the projectile or its wreck was deposited. This hole was surrounded by a cone of broken and shattered material which started at or below the bottom of the cylindrical hole and enveloped the actual cavity. The depth in solid limestone and sandstone, at velocities at which the best cast iron shot would break up, and estimated, from the powder charges used, to be somewhere about 1,800 feet per second, was a fraction under two diameters of the projectile used. The depth was observed to increase much more slowly than the velocity of the shot, and more slowly still after the velocities at which the shot would break up had been attained. The author has observed from direct experiment that the crater still retains its round form even when the impact of the projectile is as far removed from the vertical as twenty degrees; the only noticeable effect being the greater shattering of the side of the crater against which the angle of impact causes the projectile to bear with most pressure in its penetration. These experiments were made with a high power, small-bore rifle, having an initial velocity of about 2,300 feet per second.

CONFIRMATORY EVIDENCE OBTAINED BY DEEPER EXPLORATION
INSIDE CRATER.

As, in the judgment of the author and Mr. Barringer, the outside indications all agreed with the theory that the crater had been produced by the impact of a great meteor, it was determined to explore the interior for additional confirmation of this fact and also to endeavor to reach the main mass of such meteor. In pursuance of this object five small prospecting shafts have been put down of depths varying from 30 to 200 feet, and also five bore holes from 305 to 1,003 feet in depth. Although none of these has struck the main body of the meteor, ample confirmatory evidence of the theory of the meteoric formation of this hole has been obtained.

Rock in place in the bottom of the hole has been struck, in the opinion of the author, in two places. First, in shaft No. 2, 510 feet from the center of the hole, in a direction fifteen degrees north of east from the said center and at a depth of 147 feet; and secondly, in bore hole No. 5, at a distance of 250 feet southeast of said center, at a depth of 890 feet. The shaft penetrated the rock in place fifty-three feet and the bore hole 113 feet. In the shaft the rock, while undoubtedly in place, had been so crushed and disintegrated that its substance was that of a bed of loose sand. But the planes and marks of stratification were complete and unbroken and showed an upturning of the crushed, previously level strata to an angle of about forty-five degrees in a direction away from a point slightly north of the center of the hole. In other words, this rock in place dipped downward and outward, closely corresponding to the rock exposed in the walls of the crater above, but was much more shattered and disintegrated.

The rock in place, penetrated by the drill hole, could be distinguished only by its hardness, and, of course, its condition could not be examined. In both cases the rock was sedimentary sandstone without any sign of heat action whatever, either volcanic or by the action of hot water.

The general description of the filling material in the deeper portions of the hole is as follows: For a distance of 60 to 100 feet from the present bottom of the crater, about its center, the hole is filled with sedimentary material evidently deposited in the bottom of shallow water. It is stratified horizontally, as though the sediments had been washed down from the surrounding walls, either by successive wet seasons or successive violent rain storms, and has been deposited in approximately level sheets by wave action in shallow water. This stratified material is full of small shells of various kinds, and contains

a number of hard level strata a few inches in depth running through it, as though at times the water had disappeared and the sediments had become baked and indurated by exposure to the sun. Around the sides of the crater this sedimentary filling is much shallower, and its bottom is marked by a bed of broken rock talus which extends outward from the edge of the central plain, dipping towards the center at about six or seven degrees. How far this talus extends is unknown, but at 400 feet from the edge of the central plain it is forty-seven feet beneath the surface and about twenty feet thick. In the neighborhood of the center of the hole this sheet of broken rock does not exist over an undetermined area, in which the sedimentary deposit was considerably deeper than around the edges to the depth above noted. Below the sedimentary deposits in this central area, and underneath the talus elsewhere, the crater is filled with powdered rock of an almost impalpable fineness. In some places this is snow-white and contains over 99.5 per cent. silica. Elsewhere it is of a slightly yellowish tinge, and in places is cemented together by redeposited carbonate of lime. Down to 300 feet below the interior plain there is no change in this material. Through it is scattered sparingly fragments, more or less shattered, of the three strata penetrated by the hole, namely, red sandstone, yellow limestone and white sandstone. There is no order of their deposition, but the three materials are mixed indiscriminately. In shaft No. 2, however, at a depth of sixty-seven feet, there is a series of boulders, scattered rather thickly through the powdered silica for about twenty-five feet in depth, in which the natural order of occurrence of the rocks is exactly inverted. That is, fragments of the surface red sandstone are the deepest, above which come fragments of the middle strata of yellow limestone and at the top are situated fragments of the deepest strata of white sandstone. This formation suggests the idea of the surface material, having first received the impact of the meteorite, started first on its aerial flight, followed by the lower materials in turn as they were reached, and retained this order when falling back into the hole as it was being filled up.

In the central portions of the hole, below 300 feet, the proportion of broken and unbroken sand grains among the powdered silica begins to increase perceptibly, and slightly below this point meteoric material, of a character which will be described below, begins to be noticeable. The filling material continues to get coarser and coarser and contains more and more meteoric material with the increasing depth until the 500-foot level is reached. This point is 900 feet below the former level of the rocky plain at this point and about 1,100 feet below the crest of

the rim at its highest point. At the 500-foot level there is but little powdered silica; the material is mostly of broken and unbroken sand grains. Below this point the powdered rock is again met with which is very fine. It is almost, but not quite, as fine as at the surface. This change occurs quite suddenly and is accompanied with a progressive scarcity of meteoric material which is completely absent at 550 feet. From this point down there is again a gradual increase in whole and broken sand grains contained in the material, and at 860 feet it changes color quite suddenly to a reddish-brown sand, which at 890 feet, from the sudden change in hardness and the difficulty of drilling, is almost certainly rock in place. This continues to the farthest point reached, namely, 1,003 feet below the level of the interior plain.

It is submitted that, regardless of the fact of whether or not the last 100 feet is solid rock or not, that the material penetrated for the last 150 feet must be rock in place; for this reason: The change from white sand to reddish-brown sand is quite marked and sudden, and if this material had been stirred up by the passage of any projectile through it, it would have been so mixed as to be indistinguishable, or at any rate would certainly not have had a definite boundary line between the two materials. For 180 feet below the surface of the plain the filling material is absolutely dry. At this point dampness is perceptible, which increases with the depth until at 200 feet the material is nearly saturated with water; which fact determined the stoppage of the shafts at this point and the use of well-drilling apparatus for the deeper explorations.

METEORIC MATERIAL FOUND IN THE LOWER PORTIONS OF THE HOLE.

The meteoric material found, mixed with filling material, in the hole from the 300- to 500-foot levels is of the following kinds: First, magnetite in the form of scales, closely resembling hammer slag produced by a blacksmith in welding and forging iron. These films occur in varying proportions among the sand. Second, of more sparing occurrence are small particles of brownish magnetite, resembling that picked up on the surface. Third, sand grains wholly or partially coated with magnetite and small bunches of sand grains cemented together with magnetite. The first and third forms have undoubtedly solidified from a state of fusion; the first alone, and the latter when the fused magnetite came in contact with one or more grains of the sand. The appearance of this last form under the microscope is precisely that of broken stone smeared with, and cemented together by, such a fused material as asphalt when prepared for the foundation of an asphalt street. Second,

silicate of iron in forms exactly duplicating the first and third forms of the magnetite above specified; that is, in films and adhering to sand grains. This material was at first thought to be magnetite on account of its exact similarity in appearance, except that it was of rather a darker color. But it was distinguished from magnetite by observing its almost complete indifference to the magnet. Analysis confirms this fact, and these blackish scales leave a snow-white skeleton of gelatinous silica of the shape and size of the original fragment on prolonged boiling in hydrochloric acid.

It is supposed that this material was formed when the fused magnetite and silica from the powdered rock were mixed together at a heat sufficient to cause combination. Both these forms contain but a very small proportion of nickel, and as they both occur below the water level in the silica it is probable that the greater portion of the nickel has been leached out of them, on account of the greater solubility of the nickel oxide and the extreme fineness of subdivision of the material. Third, there has been found among the filling material in a few localities, but much more sparingly than the magnetite or the silicate of iron, small round globules of metallic iron surrounded by an envelope of magnetite. These small globules range from one-twenty-fifth to one-fiftieth of an inch in diameter. While it is conceivable that silicate of iron and magnetite might occur in the wreck of terrestrial strata of the character found in this locality, it is extremely improbable, because there is no trace of any of this material in the unpulverized rock forming the strata in question. But it is absolutely inconceivable that these little metallic spheres with their coating of magnetite could exist in any sedimentary strata, such as alone occur in this locality. Small particles of terrestrial metallic iron have, as is well known, been found in certain localities, but not in rock of this nature. And they could not have resisted complete oxidation if the original rock in which they were found had been weathered away and its material subsequently formed into sandstone. Moreover, if they had resisted such complete oxidation, the coating which would form around them would be ordinary hydrated sesquioxide of iron and could not be magnetite. And also such metallic iron as has been found in terrestrial strata has always been found in strongly basic rocks. Whereas the rocks in this locality are extremely acid, in fact almost pure silica.

Two other remarkable phenomena have been noted in the water pumped from these bore holes. This water is clear and without taste or odor, but it contains a small amount of flocculent gelatinous silica floating in it. Also in several places, and it was noted that these places

were at the levels at which most of the other meteoric material was found, the first water drawn from the hole in the morning, after standing over night, was found to contain a very considerable amount of dingy green protoxide of iron suspended in it, which upon exposure to the air rapidly oxidized and became converted into a reddish-brown hydrated sesquioxide. The only explanation that can be offered for these phenomena is that, probably, the extremely thin films of silicate of iron have had their iron dissolved by long immersion in water containing carbonic acid, leaving their gelatinous silica skeletons suspended in the water, and that the solution of carbonate of iron may later have lost its carbonic acid in some way, possibly by absorption by lime from the limestone strata, and precipitated out of the protoxide of iron which remains in suspension in the water. It has also been noted that from the deeper portions of the hole, below 600 feet, where the meteoric material has not been found, that the sand itself showed a very minute trace of nickel, which has probably come from the leached meteoric material above it.¹

THE POSSIBLE ENCOUNTER OF LARGER METEORIC MATERIAL.

The small prospecting shafts above referred to were stopped by water at 200 feet before penetrating to levels at which later explorations showed the meteoric material was to be encountered. This stoppage was caused by their small size and their light timbering, which

¹Since this article was written, the author has discovered the presence of a small amount of very finely divided metallic iron among the silica. This has been found, so far, in every sample examined, from the north and south rims as well as from the filling of the central plain. It varies in amount, but its proportion is extremely small. The largest amount has been found among the silica from the filling of the crater, where it exists to the proportion of nearly a quarter of an ounce to the ton. From the north and south rims the amount is less in the order stated; from the south rim it does not amount to a twentieth as much as from the interior of the crater.

This metallic iron was detected, separated and estimated as follows: The silica was passed through a magnetic separator and a very small amount of magnetic material of a dark color collected and weighed. A weighed portion of this was carefully ground in an agate mortar, wet and the finely powdered material washed away from time to time until the material was reduced to about one-tenth of its original bulk. In this residue, by the use of a glass, could be observed a great number of bright, white, shining metallic scales and spangles. They were strongly influenced by a magnet. A solution of copper sulphate was then poured over this residue and the bright white spangles were observed to turn dull red-copper color at once. The finer portions were then observed to be indifferent to the magnet, although the larger ones were still attracted. On prolonged treatment all became indifferent to the magnet. The residue was then washed and the copper in it determined, there being none in it before treatment. As a check the iron was determined in the copper sulphate solution used and wash waters, the solution being pure. Distinct traces of nickel were also observed in this material.

rendered them unfit to penetrate strata in which pressure tending to crush them would be encountered. The five bore holes were all put down within a very small area. Their object was to find out how far down this hole extends. This object was attained by the fifth alone. Three of the previous holes were stopped by encountering substances which, although not determined with certainty, were in all probability larger fragments of the great meteor. The first was found in bore hole No. 1 under the following circumstances: This hole had been put down about 300 feet, being four inches in diameter, when the piping stuck, and a two and one-half inch pipe was then put down to 420 feet and there stuck. A one and one-fourth inch pipe had been put down 630 feet and withdrawn owing to a change in drillers. The hole thus remained idle for some ten days. On resuming work it was found to be filled up to about 380 feet, that is to about forty feet above the end of the two and one-half inch casing. When the drilling was resumed the small pipe very rapidly cleared out the casing and the hole below until it arrived at 480 feet, where it encountered an obstacle that could not be penetrated, although the hole had previously been 150 feet deeper. Against this obstacle the drill was kept rotating two days. It was so hard that it was penetrated less than two inches and would dull the drills almost immediately. It was while rotating upon this obstacle that brown magnetite, resembling that found upon the surface, was gotten from the hole and also the greater number of little iron spheres with magnetite coverings. The obstacle proved impossible to penetrate, and it was attempted to remove it by jetting large quantities of water and also dropping the bit upon it as hard as could be done with so small and weak a line of pipe as one and one-fourth inch, and by this means it was after a long time forced down nearly a foot, thus proving that it was a comparatively small object. As it was impossible to get through it or around it, this hole was then abandoned. The one solution of this matter can be that the hole passed very close to a small fragment of meteoric iron or magnetite when it was first put down, and that the subsequent washing of water through the hole had loosened up this object, which subsequently, by the caving of the hole, slid across it and effectually stopped further progress. The next hole, No. 2, was stopped in much the same manner by an obstacle of apparently the same character at 300 feet. This hole was, however, using a four-inch pipe, and on this account and its less depth the object was much more accessible. Much less magnetite and other meteoric material was obtained from this obstacle than from that in No. 1. It wore out the tempered steel drills in the same way. A drill with chisel edge was

then put in and the strong and heavy pipe line, weighing about 3,500 pounds, was then dropped on this obstruction a great number of times. It was driven a very small fraction of an inch each time, possibly between two and one-half and three inches in all. The pipe line was dropped about eight feet each time, which was as much as it would stand without collapsing. And each time the drill struck the obstruction it would ring with a clear metallic sound and rebound some eighteen inches to two feet. This was almost certain proof of the metallic nature of the obstacle, as stone would have crushed and given a dead impact without appreciable rebound.

A small magnet of about half pound in weight was then lowered down the hole on the end of a string. This magnet repeatedly attached itself to the sides of the iron casing in going down, so that ample opportunity was offered to feel the pull necessary to detach it from adhering by its own magnetism to a piece of unmagnetized iron. The pipe casing during this trial was lifted some fifteen to twenty feet above the obstruction. When the magnet passed below the end of the pipe casing it descended perfectly free until it reached the bottom, where it attached itself very firmly to whatever object obstructed the hole, and required a pull of several times as much force to detach it as was necessary to detach it from adhering to the pipe casing at nearly the same depth, and consequently with nearly the same weight of line supporting it. This was repeated many times and there was no doubt about the facts as stated. It was then endeavored to get an impression of the bottom of the hole, but suitable material was not at hand and the impression was not very satisfactory, although it seemed to show a flat bottom to the hole with a crack about one and one-fourth inches wide and of unknown depth with roughly parallel edges across the bottom of the hole. This shape was not like anything observed on any of the surface irons, but was less like what might be expected in a rock boulder. This crack caught the drills and made it almost impossible to rotate upon this obstruction. The magnet brought up a small quantity of iron chips, some of which were undoubtedly from the pipe, having been cut from it by the machinery for rotating it, but others seemed of different nature and fracture from either pipe chips or the steel of the drill, which, moreover, had not lost material of this size and shape. They were thought to be meteoric iron. On analysis the mixed metallic iron gave .4 per cent. of nickel. As the greater proportion of this iron was undoubtedly composed of pipe chips, free from nickel, this was thought to be strongly confirmatory of the probability of the fact that the doubtful material was actually meteoric iron.

The pipe was then withdrawn and three sticks of No. 1 dynamite put down into the hole, in contact with this obstruction, and there exploded. This explosion, which would have certainly shattered any boulder small enough to have been driven by the pipe line even in the open air and much more so under 100 feet of water tamping, had no effect whatever upon the obstruction, except to drive it downward about two inches; and when the pipe was put back into the hole and again dropped on the obstruction it still bounced and rang as before. This hole was then abandoned. Hole No. 4 encountered an obstacle of this kind at about 400 feet which threatened to stop the hole. But from the wear of the drills it was suspected that the obstacle did not cut off all of the hole, and it was found that a two and one-half inch pipe would pass this obstruction which had stopped a four-inch pipe, and this hole was continued down to 600 feet where it was lost for other causes. The last hole, No. 5, did not encounter any such obstacle and was the only one which attained the object of all of them, namely, to find if possible the bottom of the hole. This object having been attained and the five prospecting bore holes proving exceedingly tedious and expensive and the results more or less uncertain, it was determined to abandon this method of proceeding and put down a shaft properly equipped for penetrating the wet ground. This has been done to a depth of 180 feet, and further progress now awaits the installation of the machinery.

The author feels that he can announce the following facts as absolutely proved:

First: That at this locality there is a great hole or crater in the earth which corresponds in all respects, except in its gigantic scale, with impact craters formed in rock by projectiles of considerable size moving at considerable velocities.

Second: That in and around this hole and below its bottom to a distance of over 1,400 feet below the present surface of the plain surrounding it, and the original surface of the place where this hole was formed, every indication of either volcanic or hot spring action is positively absent.

Third: That in and about this hole all signs which might be expected of the impact of such a great projectile are present.

Fourth: That upon the surface of the rim and upon the surrounding plain there has been found and still exists a large quantity of meteoric material, and that the distribution of this material is symmetrical with a line passing through the center of this hole.

Fifth: That this meteoric material was deposited at the same instant of time at which the hole was made.

Sixth: That in and around this hole is an enormous quantity of pulverized rock, produced from the strata penetrated by the hole, in a state of subdivision which can be produced by a violent blow, but cannot be produced by forms of natural erosion.

Seventh: That there can have been no form of natural erosion active in this locality which would have produced this material and have collected it and retained it in the position in which found.

Eighth: That meteoric material has been found among the filling material of this hole at a depth of 900 feet below the surface of the original plain, and 500 feet below the present bottom of the crater, and 400 feet below the surface of the material which fell back into the crater at the instant of its formation.

Ninth: That all of the attendant minor phenomena observed can be explained upon the theory of the impact of a great projectile, and none can be satisfactorily explained upon any other theory.

In view of these positively established facts, the author feels that he is justified, under due reserve as to subsequently developed facts, in announcing that the formation at this locality is due to the impact of a meteor of enormous and hitherto unprecedented size.

DATE OF THE OCCURRENCE.

Fortunately there is a means at hand of obtaining a very good idea of the age or rather the extreme recentness of this phenomenon. That is, aside from the evidence of the hole itself and the lack of erosion of the sharp edges of the ejected rocks themselves, and this in a country of desert sand and furious winds, in which all exposed rocks are rounded and sculptured by wind erosion to a marked degree. This evidence comes from a little red sandstone butte some half a mile north of the north edge of the hole. This, as mentioned in the earlier part of this paper, is a portion of what was once the covering rock of this country and which can be seen at a glance to be in process of rapid removal. Now it happens that a jet of the crushed material and broken rock a little more vigorous than most has fallen across this butte, and it can be traced up the near slope and across the top. Then there is an interval of fifty feet or so in the lee of the hill upon which none was deposited owing to its horizontal velocity, and then it begins again on the plain beyond for a few hundred feet until it terminates. Now this deposit up the near or southern side of the butte, in spite of the evidently rapid erosion to which it is subject, lies on the surface right up to the cap, without any red sandstone material having fallen or having been washed down upon it. From its appearance it might have been depos-

ited yesterday. This will give a superior limit of time within which the fall must have occurred from whatever rate may be assigned to the erosion of the red sandstone buttes. The author would name 10,000 years as the utmost possible limit which could be allowed, and feels that this is much too liberal and that something well inside of 5,000 years is much more nearly in accordance with the facts. In fact, so recent is the appearance of everything in this locality that some stunted cedars, growing on the rim and showing year rings of over 700 years of growth, are not without value in placing a minimum limit within which the fall cannot have occurred.

SIZE OF THE METEORITE FORMING THE HOLE.

Of this it is extremely difficult to form any idea from data which would stand critical examination. Professor Gilbert put the necessary minimum as the equivalent of a sphere of 750 feet in diameter, and the probable size as equivalent to a sphere of 1,500 feet in diameter. This seems to the author as most excessive. The problem contains too many unknown factors to make calculation much, if any, better than guesswork. The following facts may be considered as having some bearing in assigning a possible maximum size to the projectile. The artillery tables above referred to give a penetration of something less than two diameters in solid limestone rock for shot at about 1,800 feet per second. Now, from the probable absence of meteoric material in the hole below 500 feet, this is assumed as about its limit of penetration. This corresponds to a penetration of about 900 feet of solid rock on the whole considerably softer than limestone, and would therefore correspond to a sphere of considerably less than 450 feet in diameter, if the velocity were not in excess of 1,800 feet per second. Now what this striking velocity was can only be guessed at, although it is absolutely certain that it was in excess of 1,800 feet per second, in all probability many times in excess of this figure; and it must be kept in mind that the energy would increase as the square of the velocity, and that the cubic contents of the hole excavated would vary directly with the energy exerted. Therefore if the velocity was 9,000 feet per second, or five times that quoted above, a sphere of one-twenty-fifth the weight of the above would deliver the same amount of energy and therefore probably make the same sized hole. The original velocity of any such body is reasonably well known from astronomical considerations and it probably struck the atmosphere at between nine and forty-five miles per second, depending upon the direction of its motion in relation to the motion of the earth. We know that this excessive velocity is very soon

dissipated in the smaller meteorites and that they strike the earth with a very moderate velocity; but could such a thin layer as the atmosphere deal in the same manner with a large body? The author is of the opinion that it could not, and that this body probably struck with a large part of its planetary velocity, and that it was extremely small in comparison with anything that would be deduced by assuming for it any such striking velocity as has ever been produced in a terrestrial projectile; but as and for the reason set forth above, he does not feel justified from any known data in naming any definite figure in connection therewith.

THE COMPOSITION OF THE METEORITE.

The composition of the outer surface, at least, of this meteorite is fairly well known and appears to have been fairly constant. For the great numbers of specimens picked up around the hole, which must have come indiscriminately from all points of the surface, are of fairly constant composition. That is, metallic iron with very small percentages of carbon, sulphur and phosphorus, with between seven and eight per cent. of nickel and a trace of cobalt. This metallic mass carries about three-fourths of an ounce per ton of platinum and iridium.

As to the interior composition of the meteorite, nothing definite can be known. If the body was a fragment the probability is that it was homogeneous throughout, as there is little or no difference between the fragments from all portions of its surface. If, however, the object was a small spheroid its interior might differ considerably from that of its exterior. It seems improbable that the mass contained any notable proportion of stony material, as nothing of this kind has been observed in the fragments around the rim, nor has prolonged and careful microscopic examination of a very large number of samples of the filling material of the hole from all depths shown anything but the broken débris of the strata penetrated, except the above-mentioned meteoric material, which is all either metallic iron or the direct results of its combustion or union of such products of combustion with the surrounding silica. It is, however, to be noted that a small stone meteorite of several pounds in weight, containing metallic iron sparsely scattered through it, was picked up by Mr. Barringer about two miles from the crater. There is, however, excellent reason for the belief that this object was observed to fall during the winter of 1903. In any event, although the iron contains a proportion of nickel somewhat less than that in the fragments of the great meteorite, yet, after careful and repeated examinations, it has been proved that the metals of the plati-

num group are certainly absent from this material. Now, although it is conceivable that a stony meteorite containing metallic iron might under some circumstances, such as prolonged heating in a reducing atmosphere, acquire a superficial coating of iron, yet it is entirely inconceivable that such a coating, concentrated upon the surface from a stony interior, could contain a definite and constant proportion of metals of the platinum group and yet leave the iron still contained in the mass entirely without any such constituents. Mr. Barringer's account of these unusual formations at Coon Butte immediately precedes this paper.

ADDITIONAL ARGUMENT AGAINST THE THEORY OF A STEAM EXPLOSION.

Eighth: Even if a steam explosion could have produced the silica dust it would have blown, as Mr. Tilghman points out (see page 899), such finely divided material high into the atmosphere, after the manner of the great Krakatoa explosion in 1883, and a very large portion of this material would certainly have been carried away by air currents and finally deposited far from the crater, instead of in the crater or on the exterior slopes of the mountain immediately surrounding it, where finely pulverized material is distributed in enormous quantities in such a manner as to warrant the belief that it and the rock fragments contained in it behaved not unlike a liquid when they were expelled by some force out of the crater. Again, the dust or minute particles or filaments of volcanic glass expelled from the volcano of Krakatoa were not only certainly of igneous origin, but when examined under the microscope were in every case found to be more or less round in shape, instead of being sharply angular particles of crystalline quartz, due, as is safely assumed, to the disintegration or rather pulverization of sand grains.